AN-1281
APPLICATION NOTE

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Amperometric/Potentiostat Measurements Using the ADuCM350

INTRODUCTION

The ADuCM350 is an ultralow power integrated mixed-signal metering solution that includes a microcontroller subsystem for processing, control, and connectivity. The processor subsystem is based on a low power ARM Cortex™-M3 processor, a collection of digital peripherals, embedded SRAM and flash memory, and an analog subsystem which provides clocking, reset, and power management capability.

The ADuCM350 is specifically designed for high precision analysis of electrochemical reactions.

This application note details how to set up the ADuCM350 to perform amperometric/potentiostat type measurements on an RC sensor which models a typical electrochemical cell.

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REVISION HISTORY

2/14—Revision 0: Initial Version

AFE AND BASIC LOOP THEORY DETAILS

ANALOG FRONT END

The ADuCM350 analog front end (AFE) data acquisition loop consists of an excitation buffer amplifier loop, transimpedance amplifier (TIA), and switch matrix. The switch matrix is a programmable interface with an external sensor configuration and a calibration resistor.

The excitation buffer amplifier loop

- Sources necessary sensor excitation current by buffering the filtered DAC voltage.
- Provides gain to the AFE excitation loop to accurately set the sensor excitation voltage.
- Provides feedback capacitors and resistors in conjunction with the gain from the excitation buffer and places a zero in the loop to increase the gain excitation frequencies.
- Provides high impedance inputs for accurate sensing of excitation voltage through sense access resistance of the sensor.

The transimpedance amplifier

- Provides current-to-voltage conversion for measurement by the ADC, the gain of which is set by an external resistor.
- Sinks sensor excitation current.
- Ensures accurate setting of the working electrode voltage, which is the common mode for the sensor.
- Offers antialiasing filtering preceding the ADC.

The switch matrix

- Allows calibration of unknown sensor impedance vs. an external known resistor.
- Allows measurement of sensor access resistances, switch resistances, and leakages for calibration.

BASIC LOOP THEORY

Figure 1 shows a 4-wire sensor configuration. The stimulus voltage from the DAC is conditioned and buffered to the D node. This signal is switched through AFE8 (switch D8 is closed) to the counter electrode of the sensor. The working electrode is held at a fixed common mode at AFE1 (switch T1 closed). This results in a current flow from D through the sensor to the T node. This current is converted to a voltage using the R_{TIA} on the feedback path of the TIA.

$$Current\ into\ T\ Node = (V_{COUNTER} - V_{WORKING})/Z_{SENSOR}$$

$$Voltage\ seen\ at\ ADC = Current\ into\ T\ Node \times R_{TIA}$$

The sensor is also being sensed differentially by P and N nodes. Both P and N are fed back into the feedback loop of the excitation stage through an instrumentation amplifier using AFE6 (switch P6 closed) and AFE3 (switch N3 closed). The excitation amplifier loop forces the differential voltage across the sensor (AFE6 to AFE3) to be equal to the DAC output voltage. Both P and N switches are very high input impedance to guarantee no current flows in sense lines. This single stimulus/differential sense configuration allows for a very accurate amperometric configuration system.

For 2-wire or 3-wire sensor configurations, as seen in typical bench-top potentiostat type devices, the P and/or N sense lines can be tied internally through the switch matrix. In Figure 2, the P feedback is tied to AFE8 (switch P8 closed) and the N feedback is tied to AFE1 (switch N1 closed).

$$Current\ into\ T\ Node = (V_{AFE8} - V_{AFE1})/(R_A + Z_{SENSOR} + R_A)$$

$$Voltage\ seen\ at\ ADC = Current\ into\ T\ Node \times R_{TIA}$$

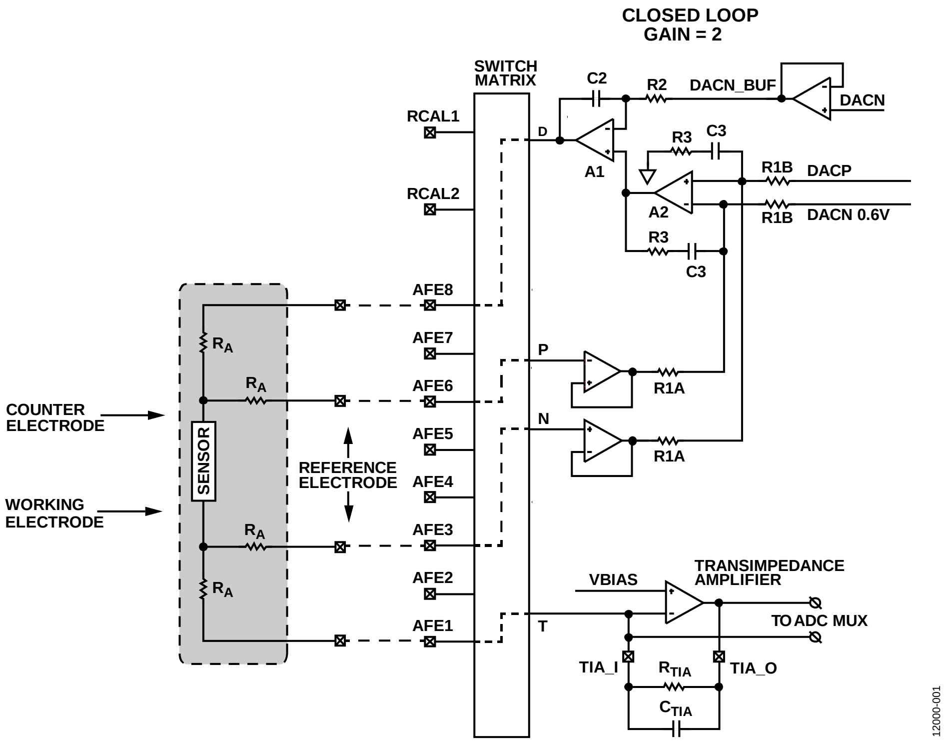

Figure 1. AFE Excitation Loop Block Diagram—4-Wire Configuration

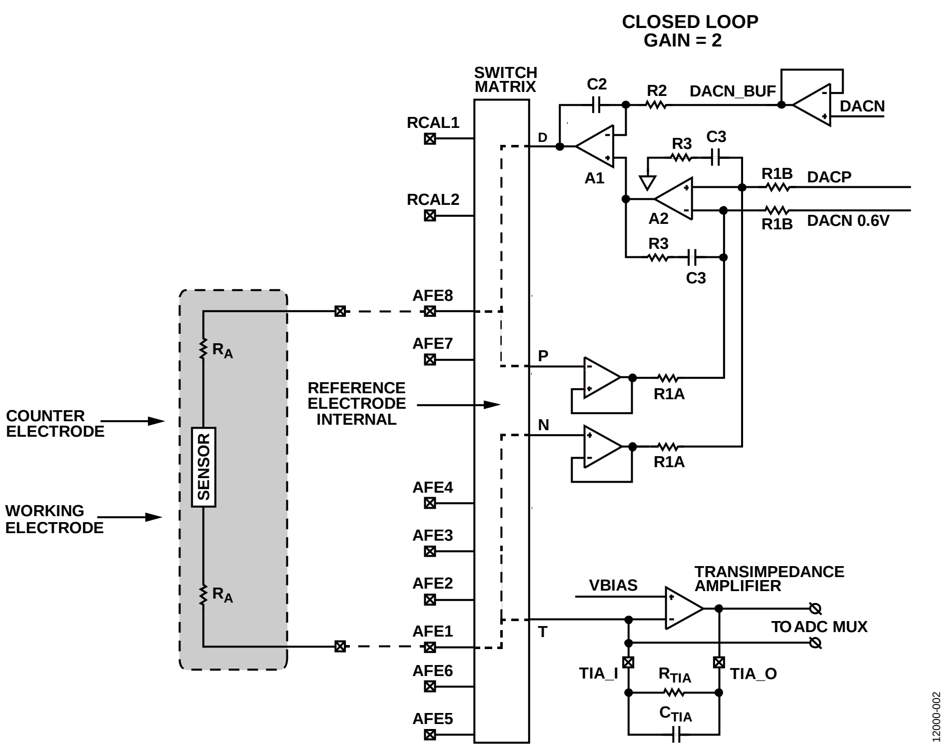

Figure 2. AFE Excitation Loop Block Diagram—2-Wire Configuration

AMPEROMETRIC MEASUREMENT EXAMPLE

The example in this section measures the current that flows from the counter electrode to the working electrode in a 2-wire sensor configuration with the RC type sensor. The configuration is shown in Figure 3.

At time zero (t = 0), the counter electrode is held at midscale (1.1 V) and the working electrode is held at a common mode of 1.1 V (VBIAS) so that no current flows through the sensor. After 500 µs (t = 1), a 300 mV step voltage is applied to the counter electrode of the sensor (DAC is configured to output 1.4 V).

The resultant current flows through the sensor and is converted to a voltage using the R_{TIA} and transimpedance amplifier.

Note the following sensor details:

- C_S = 10 µF
- R_S = 6.8 kΩ

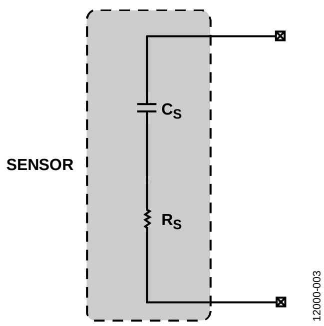

Figure 3. RC Sensor Model

Theoretical Calculations

The RC time constant (τ) is the time constant of an RC circuit. It is the time required to charge or discharge the capacitor, through the resistor by ~63.2% of the difference between the initial and final value. For an RC circuit,

$$\tau = R \times C$$

$$\tau = 6.8\ \text{k}\Omega \times 10\ \mu\text{F} = \sim 68\ \text{ms}$$

Because it is difficult to get high precision capacitors greater than 1 nF, a large capacitor is used.

This capacitor is a ±20% X5R dielectric device.

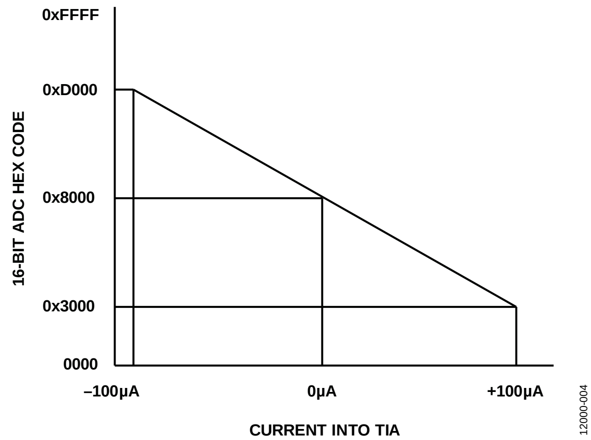

Figure 4. Ideal ADC Channel Transfer Function During Sensor/ TIA Measurement for 7.5 kΩ R_{TIA}

Figure 4 shows the ideal transfer function of the ADC for a TIA channel measurement with an R_{TIA} of 7.5 kΩ.

0xD000 – 0x3000 = 0xA000 = 40960 decimal

200 µA/40960 = 4.88 nA

This is equivalent to 1 LSB of the ADC when referred to the input current of the TIA, assuming an R_{TIA} of 7.5 kΩ.

As calculated, 4340 codes is the number of codes to reach 63.2% of V_{MAX}.

4.88 nA × 4340 = 21.1 µA

Amperometric Measurement Setup Using LabVIEW GUI

The measurement is performed using the evaluation board for the ADuCM350 and the LabVIEW® evaluation software (see Figure 5).

In the example in this section, the part is setup in 2-wire mode with D and P connected to AFE6, and T and N connected to AFE5. This is done via **AFE Switch Matrix Configuration** as shown in Figure 5.

The voltage step is programmed to go from 0 V to +300 mV, sitting on the 1.1 V system common mode.

Enabling the current voltage switch (IVS) shunts the initial current spike seen by TIA by shorting out the R_{TIA} and C_{TIA} to prevent the receive stage from railing and losing stability.

The maximum voltage that the TIA channel can measure is 750 mV p-p. A 7.5 kΩ R_{TIA} is selected for a maximum current measurement of 100 µA.

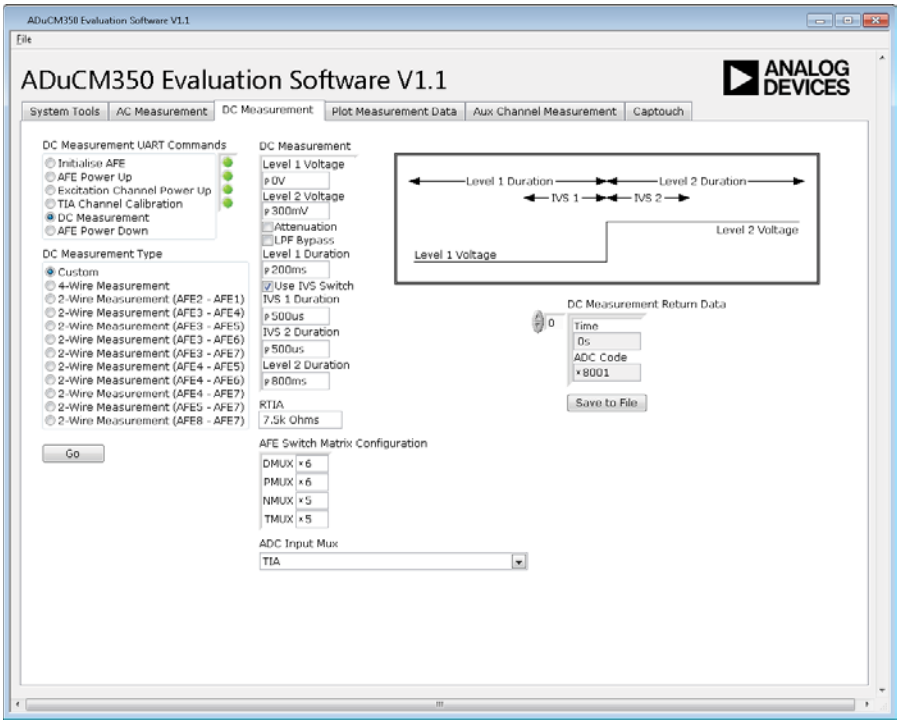

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Figure 5. ADuCM350 LabVIEW GUI Using the ADuCM350 Evaluation Kit

Select **DC Measurement** in the **DC Measurement UART Commands** window as shown in Figure 5. Once the setup is complete, click **Go** to execute a measurement.

The following two options are available to view the data:

- Go to the **Plot Measurement Data** window and select the required plot. In this example, **DC: ADC Code vs. Time** is plotted (see Figure 6).
- Click **Save to File** (see Figure 5) on the **DC Measurement** window and open the file in Microsoft®Excel.

Notice the RC step response after 0.2 seconds.

For large RC time factors, there is a settling time associated with closing the switches from all open to closed as the RC goes from floating to being pulled to a known state.

This settling is not controllable in LabVIEW because there is a fixed wait time post closing switches. It is controllable in the IAR amperomtric example. See the Amperometic Measurement.c Example in SDK section for more details.

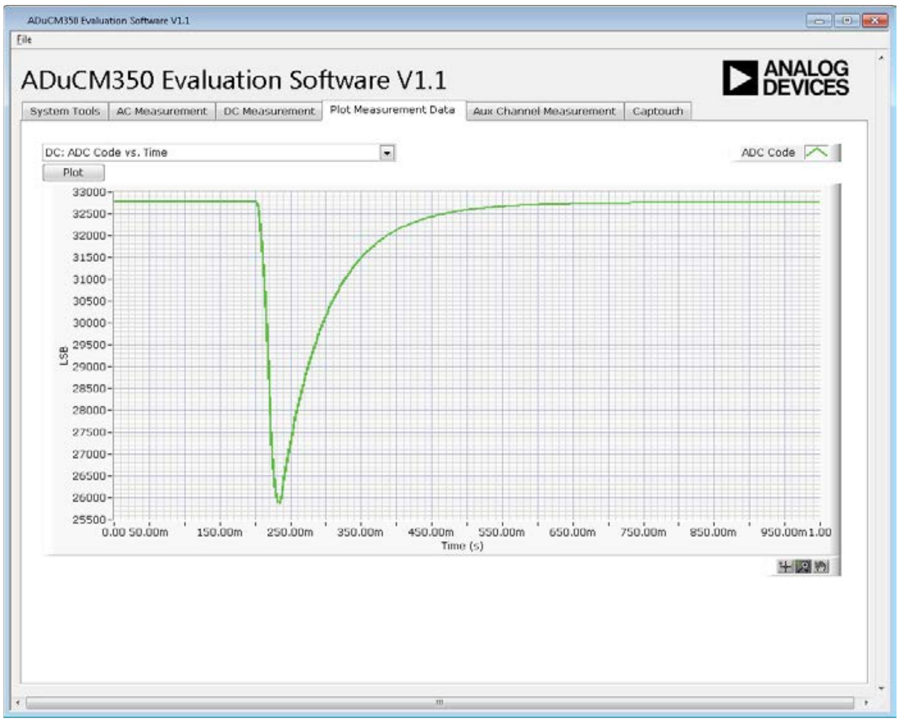

Figure 6. ADuCM350 LabVIEW GUI—Plotting ADC Results

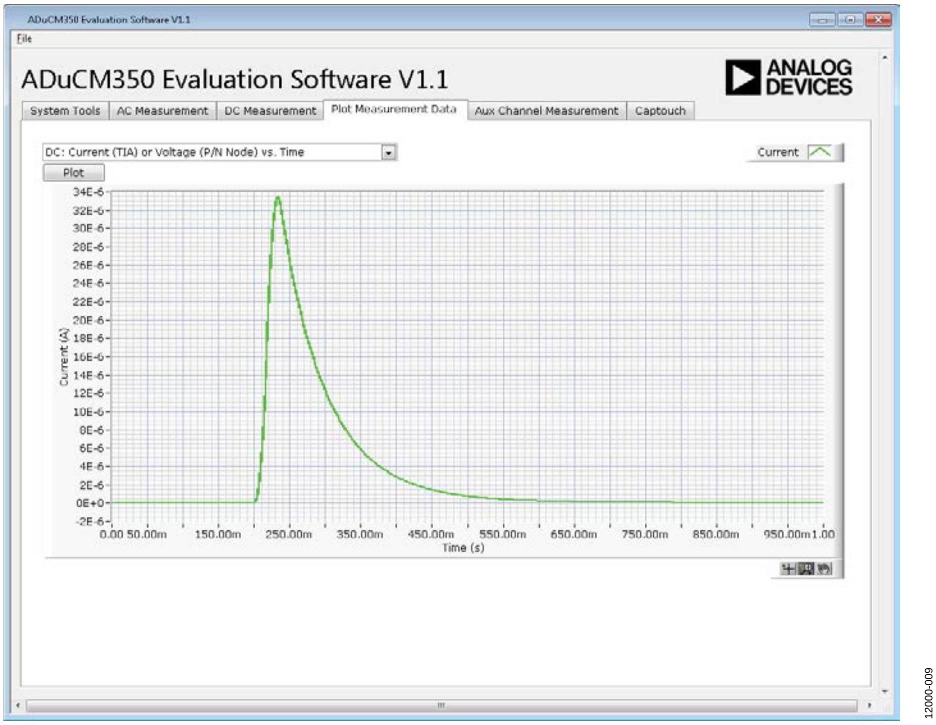

Figure 7. ADuCM350 LabVIEW GUI—Plotting Current Results

Amperometic Measurement.c Example in SDK

Locate the amperometric example project in the ADuCM350BBCZ IAR-based software development environment. For example, C:\Analog Devices\ADuCM350BBCZ\Eval-ADUCM350EBZ\examples\AmperometricMeasurement\iar\AmperometricMeasurement.eww.

See Figure 8 for details on setting up the measurement in IAR.

User controllable variables are

- DC Level 1
- DC Level 2
- Duration of dc Level 1
- Duration of dc Level 2
- IVS Switch 1 duration
- IVS Switch 2 duration
- Attenuation enable (DAC_ATTEN_EN)
- Power supply rejection filtering enable (LPFBYPASS)
- Enable IVS switching regulator

Apply a step voltage from DC Level 1 to DC Level 2. The IVS switch is enabled to prevent a current spike appearing on the TIA which could potentially rail the signal (this is sensor dependent and, thus, a good practice to include).

The number of samples is limited by the AFE DMA buffer size with a maximum limit of 1024. The ADC samples at 900 SPS; after 1.38 seconds the buffer fills up.

This buffering limitation needs to be taken into account for the timing of the step and the resulting decay.

For large RC time factors, there is a settling time associated with closing the switches from all open to all closed as the RC goes from floating to being pulled to a known state. This settling time can be captured by ADC conversions unless a significant delay is allowed post closing the switches. In this example, a delay of 400 ms is chosen to allow for the loop to settle completely (see line 111 in Figure 9). Note that if switches are not changed going from measurement mode to hibernate mode, then this delay is not required after the initial command to close switches.

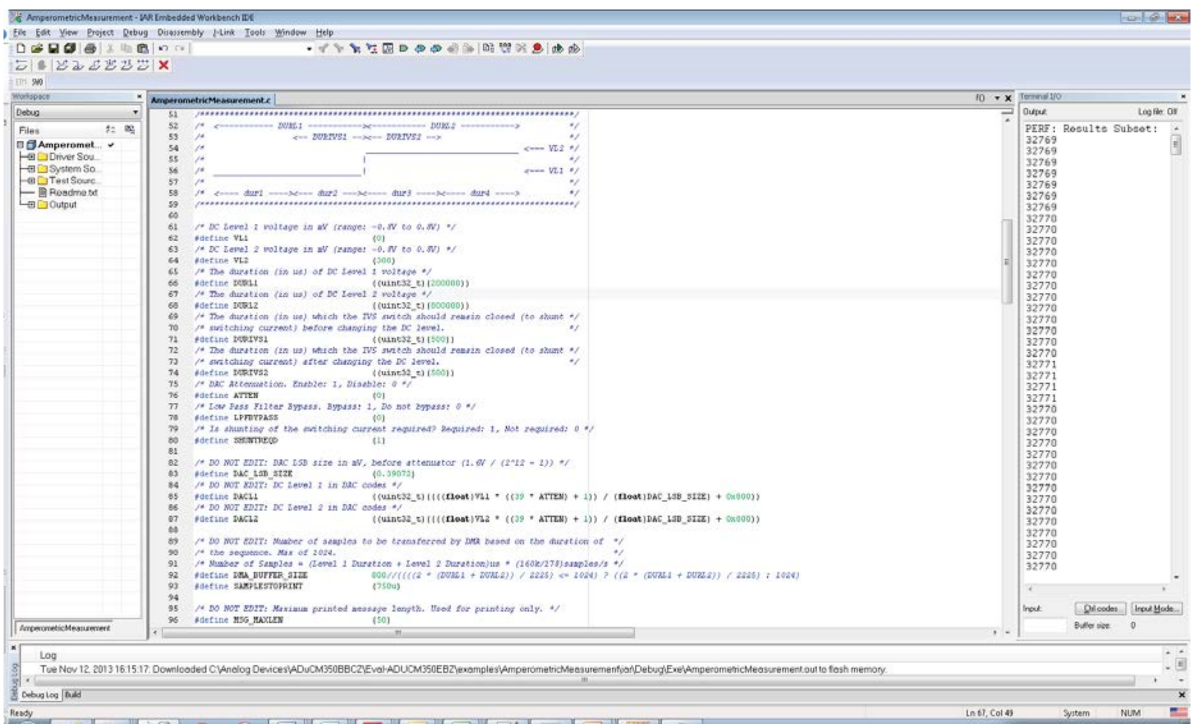

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Figure 8. ADuCM350 Amperometric Setup in IAR

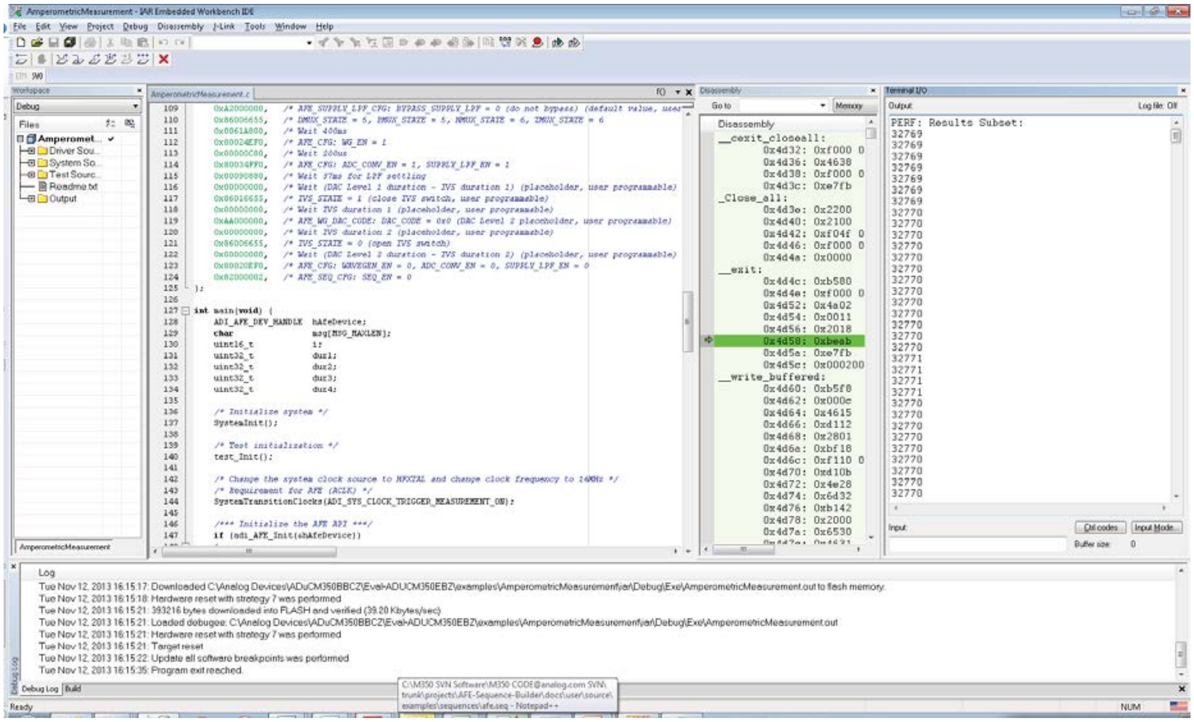

Figure 9. ADuCM350 Amperometric Example in IAR-Based Software Development Kit

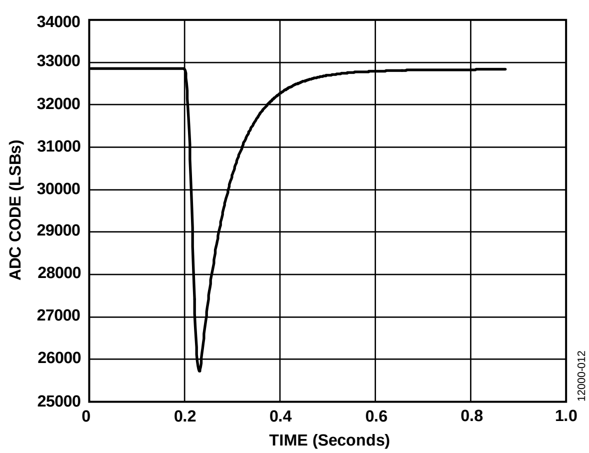

Figure 10. ADuCM350 IAR Results—ADC Code Copied from Terminal I/O Window

AMPEROMETRIC MEASUREMENT RESULTS

RC TIME CONSTANT

From actual measurements on the ADuCM350, Figure 6 plots the settling time in ADC LSBs from ~25900 codes to 32768 codes (midscale).

32768 – 25900 = 6868 codes

Time constant (τ) is the time elapsed after 63.2 % of V_{MAX} has been reached.

63.2% × 6868 = 4340 codes

25900 + 4340 = 30240 codes

Figure 6 shows an actual measurement that takes ~65.6 ms to reach 63.2% of final settling voltage of midscale.

This measured value of ~65.6 ms compares well with the theoritical value of 68 ms (see the Theoretical Calculations section for more details). The variance of the capacitor must be taken into account.

CURRENT SEEN BY THE ADC

Referring to the measured current plot in Figure 7, a maximum value of 33.5 µA is measured by the ADuCM350.

63.2% × 33.5 µA = 21.17 µA

This closely matches the theoretical measurement of 21.1 µA (see the Theoretical Calculations section for more details).

Notice that a small range of the full ADC range is used in this example. To increase the range of the ADC, the following options are available:

- Increase the step voltage magnitude. However, this may be limited for certain electrochemical cells.
- Increase the R_{TIA} value, which reduces the measurable current range. Note that the switch matrix can be configured so that the user can switch in various R_{TIA} values if a programmable gain type architecture is required.
- Considering the very slow decay of this particular sensor, another option is to use some moving averaging of the 900 SPS ADC data to increase resolution from 16-bits to 17-bits/18-bits, and so on.

NOTES